Summary of Research

Period covered by report: February 1, 1997 – January 31, 2000

"Predicting Fire Susceptibility in the Forests of Amazônia"

from

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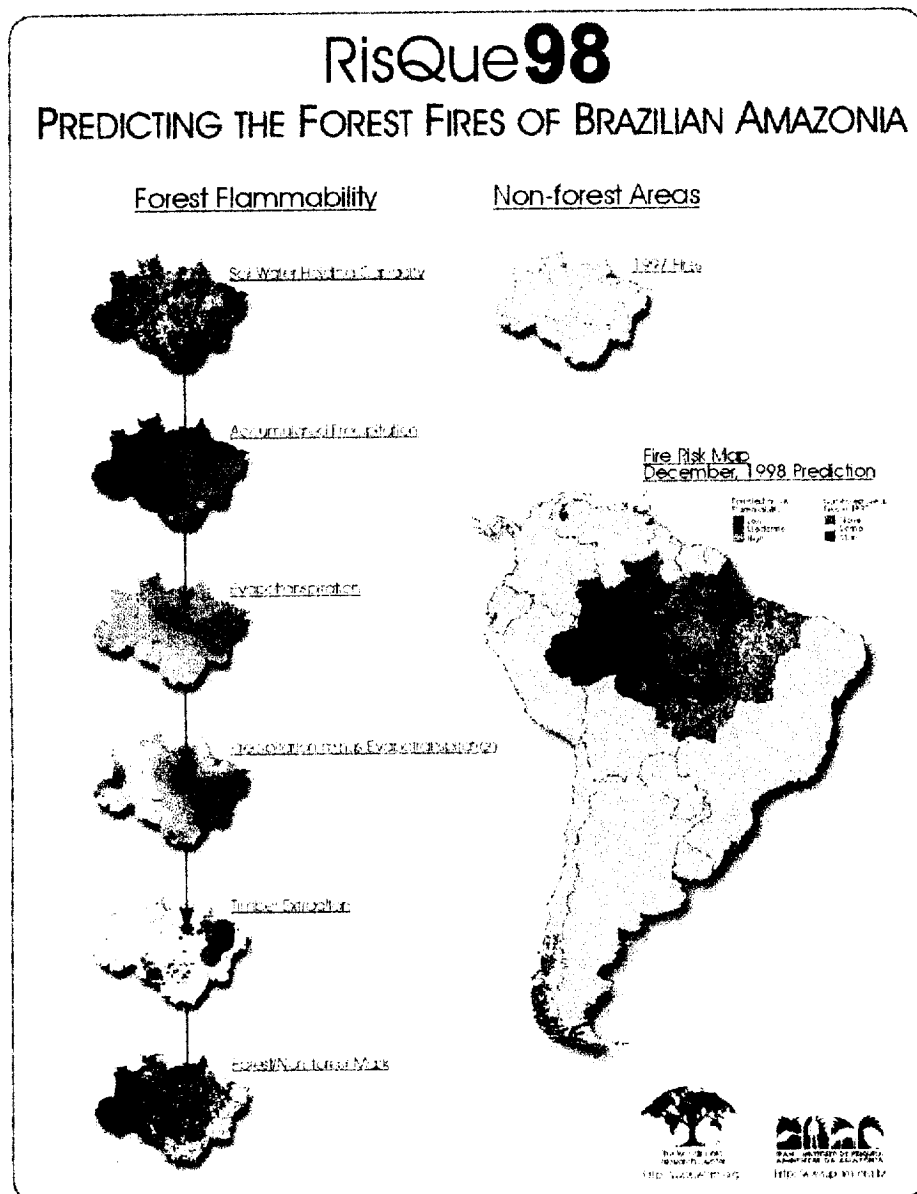Headquarters

June 1, 2000

Introduction

Although fire is the single greatest threat to the ecological integrity of Amazon forests, our ability to predict the occurrence of Amazon forest fires is rudimentary. Part of the difficulty encountered in making such predictions is the remarkable capacity of Amazon forests to tolerate drought by tapping moisture stored in deep soil. These forests can avoid drought-induced leaf shedding by withdrawing moisture to depths of 8 meters and more (Nepstad et al. 1994, Jipp et al. 1998). Hence, the absorption of deep soil moisture allows these forests to maintain their leaf canopies following droughts of several months duration, thereby maintaining the deep shade and high relative humidity of the forest interior that prevents these ecosystems from burning. But the drought- and fire-avoidance that is conferred by this deep-rooting phenomenon is not unlimited. During successive years of drought, such as those provoked by El Niño episodes, deep soil moisture can be depleted, and drought-induced leaf shedding begins. The goal of this project was to incorporate this knowledge of Amazon forest fire ecology into a predictive model of forest flammability.

Accomplishments

1. Forest Flammability: the RisQue Model

We combined regional datasets on soil texture, rainfall, air temperature and humidity, and forest cover in a Geographical Information System model that identifies those forest areas that have depleted soil moisture to 10 meters depth on a monthly basis (Figures 1). Timber extraction from Amazon forests also increases forest vulnerability to fire (Uhl and Kaufmann 1990). We have incorporated this phenomenon into the model by mapping the influence of logging in Amazônia through 1400 wood mill interviews (Figure 1). By the end of the 1998 dry season, we estimate that the severe drought associated with the 1997/98 El Niño episode had provoked severe soil depletion in approximately one third of the forests of Amazônia (1.5 million km^2) (Fig. 2).

RisQue98

PREDICTING THE FOREST FIRES OF BRAZILIAN AMAZONIA

Forest Flammability   Non-forest Areas

Fire Risk Map
December, 1998 Prediction

Figure 1: Diagram of RisQue model. Soil water-holding capacity is determined on the basis of soil texture. Water balance is calculated on the basis of rainfall and temperature data from automated weather stations. Areas of severe soil water depletion (i.e., complete depletion to 10 m depth, or only 250 mm of plant-available water remaining to 10 m depth) are mapped as flammable. Forest areas of logging activity receive an added flammability rating.

We call this model of forest flammability "RisQue", based on the Portuguese "Risco de Queimadas Florestais na Amazônia" (Risk of Amazon Forest Fires). The initial version of this model was published as a cover story in *Nature* (Nepstad et al. 1999a). This article drew extensive international press coverage (BBC, National Public Radio, New York Times, Time Magazine, ABC News, Estado de São Paulo, Folha de São Paulo, etc.), and was widely debated within Brazilian society. The article prompted Brazil's Environment Minister, Jose Sarney Filho, to declare that INPE's deforestation estimates for Amazônia would henceforth be

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considered as partial measures of human effects on Amazônia (since these estimates do not monitor understory forest fire damages). The model is also described in a short article in Conservation Biology (Nepstad et al. 1998) and in a 160-page book in English and Portuguese (Nepstad et al. 1999b). The results from this initial version of the model were also used during an Amazon conservation priority-setting workshop, held in Macapá last September

We have now completed a second version of RisQue. We revised our map of plant-available soil water by using texture-based calculations of field capacity and permanent wilting point derived from the equations of both Tomasella and Hodnett (1998) and Saxton et al. (1986), and by interpolating these maps using kriging. Our calculation of evapotranspiration was improved using a corrected version of the Thornthwaite equation developed by INPE/CPTEC scientists (Hodnett et al. 1996). Our map of deforested vs. non-deforested land in Amazônia was updated from the 1988 AVHRR-based map of Stone and Schlesinger (1994) to the 1992-1994 Landsat TM-based imagery of Skole (http://www.bsrsi.msu.edu/trfic/index.html). We have also added a new layer to the map: the number of consecutive days without rainfall of >4 mm. A manuscript describing this second version of the model will be submitted to Global Change Biology in August 2000. This model is currently being integrated with a complimentary fire prediction model developed by the Brazilian Space Research Institute (INPE, Alberto Setzer and Carlos Nobre http://150.163.132.60).

A third version of the model will incorporate forest flammability algorithms based on 500 experimental forest fires that we have conducted in four Amazon locations (Santana do Araguaia, Paragominas, Santarém, Acre). These algorithms provide empirical descriptions of forest flammability (measured as the rate of spread of experimental fires) as a function of rainfall history, leaf area index (LAI), fuel characteristics, and weather conditions. Both the second and third versions of the RisQue model have received supplemental funding from a grant we received from NASA through the Large-Scale Biosphere Atmosphere Experiment (LBA).

Two overflights were conducted to test the model predictions. We flew 800 km in southern Pará (between Marabá and Redenção) at the end of the 1998 burning season and found that 38% of the forests that we flew over had ash in the understory, or recently scorched foliage. In eastern Pará (from Belém to Imperatriz and Açailândia to the Gurupi, across Paragominas), we flew 1100 km, and found much less evidence of 1998 forest burning (5% of land surface), but vast areas of forests that had burned in previous years.
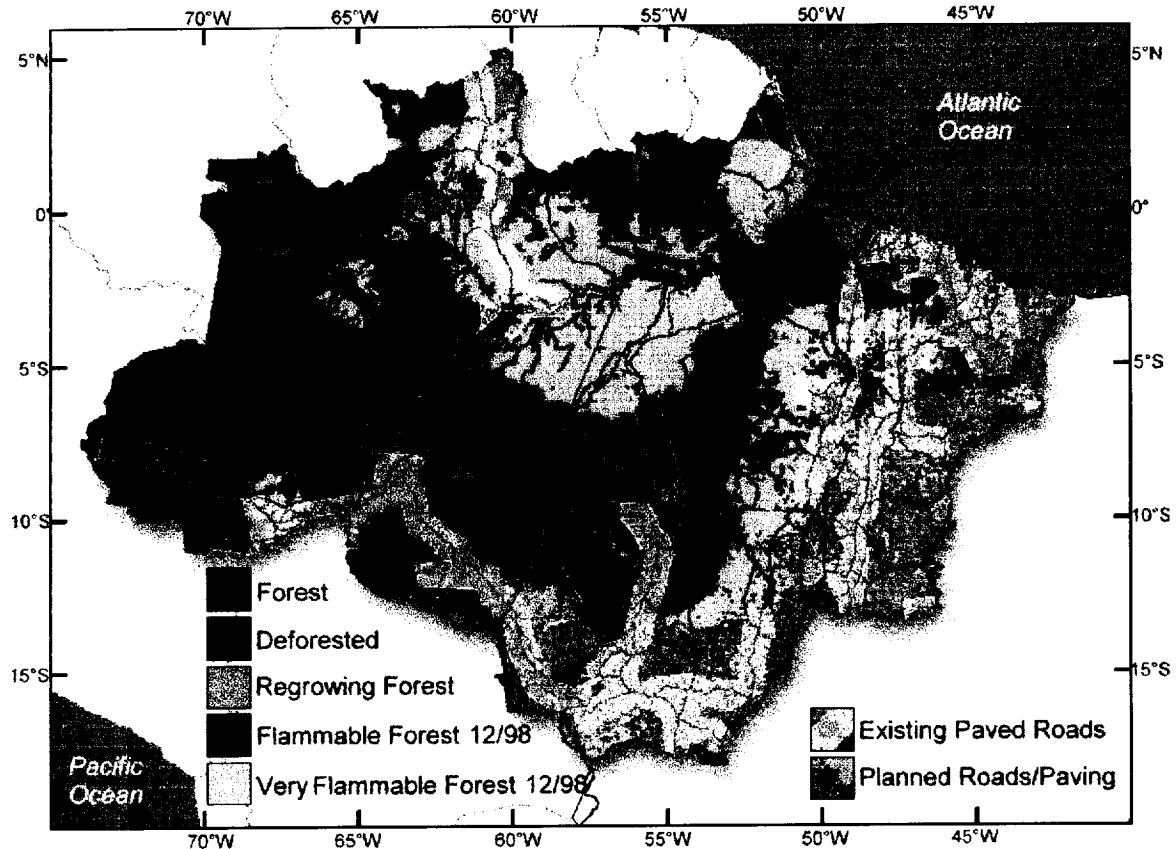
Figure 2: Flammable forests, deforested land, and roads in the Brazilian Amazon region. During the severe drought of the 1997/98 El Niño episode, nearly one million square kilometers of forest depleted plant-available soil moisture to 10 m depth, and may have become vulnerable to fire. Another half million km2 of forest depleted all but 250 mm of plant-available soil moisture. (This map is updated through December 1998 from Nepstad et al. 1999a). Most of fire-prone forests are currently protected from fire because they are far from ignition sources. However, highway paving proposed by the Brazilian government would stimulate colonization in this fire-vulnerable region, nearly doubling the amount of forestland that is within the agricultural frontier. The deforestation map is based on high resolution (28 m pixel) classified Landsat TM imagery, 1991/92; composite of 208 scenes (described in Table 2). Road A: BR-010, Belém – Brasília; B: BR-364, Cuiabá - Porto Velho; C: PA-150, Abaetetuba - Santana do Araguaia; D: BR-163, Santarém – Cuiabá; E: BR-319, Humaitá – Manaus; F: BR-230, Marabá – Rurópolis; G: BR-174, Manaus - Boa Vista

2. Sources of Ignition

Flammable forests only burn if they are exposed to fire. Since lightening ignition is rare in Amazônia (Carlos Nobre, personal communication), agricultural fires are the major source forest fire ignition. In our first version of RisQue, we have employed "hot pixels" from weather satellites (NOAA 12, 14, GOES) as a proxy variable for estimating the probability of ignition (Setzer and Pereira 1991). We assume that the close proximity of inflammable forests and the previous year's hot pixels indicates a higher probability that the forest will ignite. Using this

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approach, we can see that most of the forest that became flammable by the end of the 1998 dry season (Fig. 2) is far from agricultural frontier, and unlikely to catch fire.

We are now replacing this hot pixel proxy of ignition probability with a mechanistic economic model, that we hope will allow us to estimate the risk of ignition on the basis of rural census data. This economic model will allow us to test the impact of policy scenarios (agricultural credit, policing activities, taxation, etc.) on fire occurrence. To develop this economic model, we have embarked on an extensive field study of fire economics, through interviews of a wide range of rural producers, from subsistence farmers to large-scale ranchers. A Brazilian economist (Larissa Chermont) is developing this work as her Ph.D. dissertation, with assistance from project collaborator Joshua Bishop of the International Institute of Environment and Development (IIED). This economic study is also funded through our NASA-LBA grant.

3. NOAA Receiving Stations

The Brazilian government monitors active fires in Amazônia using hot pixels detected by the NOAA-12 and 14 weather satellites (Setzer and Pereira 1991). The National Institute for Space Research (INPE) runs this monitoring program using a receiving station in Cachoeira Paulista (São Paulo, in southern Brazil) and, as of 1999, another receiving station in Cuiabá, Mato Grosso (at the southern edge of the Amazon). It is important that other receiving stations be established to provide independent estimates of fire occurrence. For example, INPE did not release the data from the Cuiabá station during its first year of operation.

This grant has allowed us to purchase two additional NOAA receiving stations. One has been established at the Universidad Nacional Agraria de La Molina, under the direction of Prof. Carlos Llerena and Dr. Alberto Setzer. A second receiving station was purchased, and will be installed at the national agricultural research agency in Belém (EMBRAPA-CPATU). These receiving stations will provide complete coverage of active fires in the Amazon.

4. Forest Fire and Infrastructural Development

Perhaps the single best predictor of ignition sources for fire-vulnerable forests is proximity to roads. Nearly 90% of deforestation activities in the Brazilian Amazon take place within a 50 km radius of roads (Alves, in press). The Brazilian government has embarked on an ambitious road-building and asphalting program that includes more than 4000 km of newly asphalted and constructed roads in the Amazon (Nepstad et al. submitted). Nearly 200,000 km2 of forest that became flammable in 1998 will lie within 50 km of the roads that will be paved in the coming years, and . We have also estimated that these roads will stimulate 80,000 to 180,000 km2 of new deforestation, based on deforestation rates along previously paved highways (Nepstad et al. submitted). These analyses were the basis of a report released by collaborating Brazilian institutions, the Amazon Institute for Environmental Research (IPAM) and the Socio-Environmental Institute (ISA), (IPAM & ISA 2000), which was the front-page headline of Brazil's leading newspaper (Folha de São Paulo, March 19, 2000).

5. Education

This grant supported the Masters theses of Elsa Mendonza (Univ. Federal do Acre) and Ane Alencar (Boston University). It supported the Ph.D. theses of Larissa Chermont (Imperial

College, UK) and Gustavo Negreiros (Univ. of Washington). Results have been incorporated into the curriculum of the Doctoral Program in Tropical Development at the Núcleo de Altos Estudos Amazônicos of the Universidade Federal do Pará, in Belém (where Nepstad is Visiting Professor) and the Masters program in tropical resource management (Univ. Federal do Acre) where Brown is Visiting Professor. Six Brazilian BS-level interns have been trained through this grant.

6. New publications supported by this grant:

Cochrane, M. A. and M. D. Schulze. 1999. Fire as a recurrent event in tropical forests of the eastern Amazon: effects on forest structure, biomass, and species composition. *Biotropica*. 31(1) 2-16.

Cochrane, M. A. and C. M. Souza. 1998. Linear mixture model classification of burned forests in the eastern Amazon. *Remote Sensing Letters* 19(17) 3433-3440.

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Nepstad D. C., Veríssimo A., Moutinho P. R, Nobre C. A. 2000. O empobrecimento oculto da floresta Amazônica. (The hidden impoverishment of Amazon forests). *Ciencia Hoje* 2000;27:70-73

Nepstad D.C., Carvalho G. O., Barros A. C., et al. Submitted. Breaking the positive feedbacks between land use, forests, and climate in the Amazon fire regime. *Forest Ecology and Management*.

Nepstad, D, A. Veríssimo, A. Alencar, C. Nobre, P. Lefebvre, P. Schlesinger, C. Potter, P. Moutinho, E. Mendoza, E. Lima M. Cochrane, Vanessa Brooks. 1999a. Large-scale impoverishment of Amazonian forests by logging and fire. *Nature* 398:505-508.

Nepstad, D, A. Moreira, A. Alencar. 1999b. Flames in the Rainforest: Origins, Impacts and Alternatives to Amazonian Fire. World Bank, 114 pp. Pilot Program to Conserve the Brazilian Rain Forest (In English and Portuguese)

Nepstad, D., A. Moreira, A. Veríssimo, P. Lefebvre, P. Schlesinger, C. Potter, C. Nobre, T. Krug, A. C. Barros, A. Alencar, J. R. Pereira. 1998. Forest fire prediction and prevention in the Brazilian Amazon. *Cons. Bio.* 12(5): 951-953.
See also homepages: www.whrc.org and www.ipam.org

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hydrological and carbon cycles of Amazonian forests and pastures. Nature 372, 666-669.

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Nepstad, D.C., Moreira, A.G., Veríssimo, A., Lefebvre, P., Schlesinger, P., Potter, C., Nobre, C.A., Setzer, A., Krug, T., Barros, A.C., Alencar, A., Pereira, J.R., 1998. Forest fire prediction and prevention in the Brazilian Amazon. Conservation Biology 12(5), 951-953.

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